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Evolution of solar energy in India: A review

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ABSTRACT

India has tremendous potential for generating clean electricity through Renewable Energy Sources (RES) namely Hydro, Wind and Solar. This potential has been duly recognized and shows India's consciousness for reducing carbon footprint as a developing nation. Government of India with an aim to promote clean energy launched Jawaharlal Nehru National Solar Mission (JNNSM) on 11th January 2010, which is one of the eight missions under National Action Plan on Climate Change (NAPCC–2008). This mission visions to install 22,000 MW through grid connected and off grid power plants. Achieving an installed capacity of this quantum is a task full of challenges. To list the possible challenges and suggest a way forward, there is a need to study solar energy sector in India in the past, which has motivated the authors to discuss the evolution of solar energy in India since independence. Through this paper authors have tried to outline the journey of solar energy in India since 1950 till date and highlight the potential issues as barriers and challenges which could impact the ambitious mission taken up by Government of India.

This study will help decision makers and various stakeholders to understand the current status, barriers and challenges for better planning and management in the field of solar energy.

Contents

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1. Introduction

Energy is an essential input for economic development and improving the quality of life [1]. It is assessed that, earth is blessed with enormous energy, classified as conventional and non-conventional sources, for electricity generation and its use. Conventional energy sources are fast depleting and scarcity is prioritized at World level, whereas harnessing renewable energy seems to be one of the sustainable ways to meet the increasing global electricity demands.

One of the ways to sustainable growth is to generate electricity through solar energy which is cleaner and promising. Solar has the greatest energy potential among the other sources of renewable energy and the amount of energy that earth receives, as assessed by IPCC, theoretically if only a small fraction of this form of energy could be used it can meet our current needs [2] or in other words if we can use only 5% of this energy, it will be 50 times what the World requires [1] [3].

Direct Solar energy is believed to have the highest potential which can be harnessed for our use in different forms. Table 1 shows the global technical potential for all RES as assessed by IPCC [4].

1.1. Solar potential in India

India is among the leading countries having good Direct Normal Irradiance[2] (DNI), which depends on the geographic location, earth-sun movement, tilt of Earth rotational axis and atmospheric attenuation due to suspended particles. India is estimated to have huge potential for solar energy which is about 5000 trillion kWh per year [5]. The solar radiation incident over India is equal to 4–7 kWh per square meter per day [6] with an annual radiation ranging from 1200–2300 kWh per square meter [7]. It has an average of 250–300 clear sunny days [6] and 2300–3200 hours of sunshine per year [8]. Kumar [6] mentioned that theoretically, India's electricity needs can be met on a total land area of 3000 km^2 which is equal to 0.1% of total land in the country.

Therefore, technologies for conversion of solar radiation into heat and electricity, namely, solar thermal and solar photovoltaic, can successfully be exploited for providing enormous scalability in India.

Table 2 shows the total installed capacity from RES in World along with the leading countries in respective sources. It also shares the status for India along with its leading federal State. Ocean Thermal and Wave Energy are largely under demonstration phase as they still need to achieve a significant commercial breakthrough [9–11].

Government of India launched Jawaharlal Nehru National Solar Mission (JNNSM) on 11th January 2010, as one of its eight missions under National Action Plan on Climate Change (NAPCC–2008). The policy visions to install 22,000 MW through grid connected and off grid power plants. As of April 2014, India's total installed capacity through grid connected solar power plants has crossed 2.2 GW with major contribution coming through grid connected solar PV power plants. India has not been able to demonstrate significant progress through grid connected solar thermal technology. Recently a 50 MW project has been commissioned through grid connected solar thermal technology taking the total to a modest 55 MW and 140 MW has come through off grid PV systems [12,13]. This 50 MW solar thermal plant is one of the few plants which have been successfully commissioned against the total allocated capacity of 470 MW in December 2010.

These developments give a stimulus to the authors to discuss the evolution of solar energy in India since Independence.

2. National five year plan (FYP)

Five-Year Plans (FYP's) are integrated nationalized economic programs which lay the foundation plans for economy growth of a country. Planning Commission is responsible for development, execution and monitoring of FYP's in India [14]. India's first 5 year national plan was released in year 1951 [15], by the, then, Prime Minister Mr. Jawaharlal Nehru. Currently, country has just ended with 11th FYP (2007–12) and is in the first year of 12th FYP (2013–17).

2.1. 1st FYP (1950–55) and 2nd FYP (1956–60)

On assessing the 1st (1950–55) and 2nd (1956–60) five year plans it was found that the electricity generation mix in India consisted of Coal (steam), Oil and Hydro as major sources. In the

[1] The solar power where sun hits atmosphere is 10^{17} W, whereas the solar power on earth's surface is 10^{16} W. The total worldwide power demand of all needs of civilization is 10^{13} W. Therefore the sun gives us 1000 times more power than we need.

[2] *DNI is solar radiation that comes in a straight line from the direction of the sun at its current position in the sky.*

year 1950, India had a total installed capacity of 2300 MW, by the end of 1955 and 1960 the total capacity had increased to 3420 MW and 5700 MW respectively [16,17].

2.2. 3rd FYP (1961–66)

It was during the 3rd FYP (1961–66) of India that solar energy was discussed as a technology being developed World over as a source of electricity generation. The electricity generation capacity commissioned during this FYP was 10170 MW through Thermal, Hydro and Diesel [18].

2.3. 4th FYP (1969–74) and 5th FYP (1974–79)

The 4th FYP (1969–74) and 5th FYP (1974–79) had no discussion related to solar energy and thrust was laid upon Hydro, Tidal and Geothermal as priority areas for research and development in the country. The total installed capacity by the end of 4th and 5th FYP was 18,456 MW and 31,000 MW respectively [19,20].

2.4. 6th FYP (1980–85)

After almost 20 years since 1961 it was the 6th FYP (1980–85) which specifically addressed solar energy and its implementation. Developing solar energy was of particular interest for meeting energy demand of decentralized rural areas and potential industrial uses. The Department of Non-Conventional Energy Sources (DNES) was formed on 6th September 1982 as a unit under Ministry of Energy [21]. The objective of this department was to provide funding for strengthening research, development and demonstrations in the area of Renewable Energy Technologies (RET) covering all important RES such as solar, wind, bio-mass, geothermal energy etc., [22].

Table 1
Global technical potential for renewable sources.

Renewable Energy Sources	Global Technical Potential [in EJ]	
	Minimum	Maximum
Direct Solar Energy	1575	49837
Geothermal Energy [Electricity]	118	1109
Wind Energy	85	580
Biomass	50	500
Ocean Energy	7	331
Geothermal Energy [Heat]	10	312
Hydropower	50	52

2.4.1. Commission for additional sources of energy (CASE) 1981

It was formed with an objective to promote and develop RES in the country by encouraging and funding R&D activities in the said sector, through formulation of effective policies and their implementation.

CASE launched a program for manufacturing and sale of 10,000 solar cookers through subsidy, which ran in 12 States and 1 Union Territory. Also an institution called Solar Thermal Energy Centre (STEC) was established with prime objectives to drive R&D, testing and demonstration activities for solar thermal to help devices and systems to achieve commercial production. During the period of 1981–83 around 25 solar water heater systems were installed in industries like textile, dairy, bakery, brewery etc. Solar Thermal Pump (STP) was also developed jointly by Bharat Heavy Electricals Limited (BHEL) and Dornier Systems [21].

A program called National Solar Photovoltaic Energy Demonstration Program (NASPAD) was implemented through Central Electronics Limited (CEL). The program intended to bring down the cost per Watt peak (Wp) of modules through development and demonstration of low cost solar grade silicon material and improving the efficiency of solar cells for electricity generation.

NASPAD also supported CEL in R&D project of Multi-Crystalline Silicon Solar Cells (MSSC) and develop Ultra-High Efficiency (UHE) solar cells [21]. CEL was engaged in manufacturing solar PV cells and modules and it achieved a total capacity of 10.35 kW, 21.07 kW and 31.75 kW in the year 1980, 81, 82 respectively. Along with it CEL also manufactured 60 solar pumps for irrigation, drinking and water supply purposes. They also manufactured Solar PV power packages for Indian Antarctica Expedition and Oil and Natural Gas Corporation (ONGC) for their offshore activities.

2.5. 7th FYP (1985–90)

7th FYP (1985–90) saw an important development of Amorphous Silicon Solar Cell (ASSC) technology. BHEL was given the responsibility to execute a plant with a capacity to manufacture 500 kW of modules per annum and to achieve the cell efficiency of 13–15% at laboratory level [1].

2.6. 8th FYP (1992–97)

In 8th FYP (1992–97) Government of India showed the need to electrify 10,000 villages through decentralized and non-conventional methods of energy sources (such as solar photovoltaic). These villages were mostly remotely located to far-flung areas where possibility for load development was very little. Further, the plan laid importance on intensification and enlargement of low grade devices to meet the needs of cooking and heating in the rural areas of the country. In addition to this a central budget was approved to develop a 1720 kW of capacity

Table 2
Comparison of a RES with country in lead & India's status with the state in lead.

RES	World status	World leader	India status	Potential	Leader
Biomass	83 GW-2012	United States	3.7 GW – 2013	23,7 GW	Uttar Pradesh
Wind	283 GW-2012	China	17.6 GW – 2013	47 GW	Tamil Nadu
Small Hydro	–	–	3.71 GW – 2013	15 GW	Karnataka
Geothermal	11.7 GW-2012	United States	203 MW – 2013	10 GW	J&K
Solar PV	100 GW-2012	Germany	1.84 GW – 2013	4–7 kWh/km2/day	Gujarat
Solar Thermal	2.5 GW-2012	Spain	52 MW – 2013	4–7 kWh/km2/day	Rajasthan
Tidal Energy	527 MW	South Korea	No such commercial breakthrough		

Table 3
Achievements in the 10th Five year Plan.

S. No	Year	Wind [MW]	Small Hydro [MW]	Biomass Cogeneration [MW]	Biomass Gasification [MW]	Solar Power [MW]
	10th plan Target	***1500***	***600***	***700***	***50***	***145***
1	2002–2003 [Actual]	241.3	80.39	102.63	2.07	0.5
2	2003–2004 [Actual]	615.25	84.04	129.5	4.85	0.05
3	2004–2005 [Actual]	1111	102.27	136.1	8.33	1.75

through solar PV, along with solar pumps, solar lightings and solar cookers [23].

2.6.1. Indian renewable energy development agency (IREDA)

IREDA was formed on 11th March 1987 with a main objective to operate a revolving fund for developing, promoting and commercialization of New and Renewable Sources of Energy (NRSE). NRSE was financially assisted by Government of Netherland, World Bank, Asian Development Bank (ADB) and The Danish International Development Agency (DANIDA). IREDA acted as an executive agency for NRSE program in coordination with State energy development agencies [24].

2.7. 9th FYP (1997–2002)

In the 9th FYP (1997–2002) Government of India encouraged and initiated private sector participation with an objective to mobilize additional resources for power sector namely generation, transmission and distribution. Under this initiative the Independent Renewable Power Producers (IRPP) were having the right to wheel the (renewable) power through existing transmission lines of the State Electricity Boards (SEBs) on payment of reasonable charges for selling the power to any third party in the country. All hurdles in this regard were needed to be resolved so as to encourage IRPPs to make their contribution in promotion of power generation from non-conventional energy sources. Policy permitted the private developers to set up power projects of any capacity of any type (wind or solar). Greater emphasis was laid on improving the reliability and quality of power. Special emphasis was laid on electrification of villages with due attention to decentralized energy resources [25].

2.7.1. Special action plan (SAP)

In the year 1997 a Special Action Plan (SAP) was prepared for “Rapid Improvement of Physical Infrastructure”, which included the solar PV programs. These programs were promoted in areas covered under Special Area Development (SAD)[3] .

[3] *Special Area Programmes have been formulated to deal with the special problems faced by certain areas arising out of their distinct geo-physical structure and concomitant socio-economic development. Central Government is supplementing the efforts of the State Governments in this direction through Special Central Assistance under the programmes such as*

- *Hill Area Development Programme* (*HADP*),
- *Western Ghats Development Programme* (*WGDP*),
- *North Eastern Council* (*NEC*),
- *Border Area Development Programme* (*BADP*),
- *Desert Development Programme* (*DDP*) *and*
- *Drought Prone Area Programme* (*DPAP*).

Solar Energy Programs were implemented through subsidies. Ministry of Non-Conventional Energy Sources (MNES) was responsible for providing subsidy with concerned Departments/Ministries and justify the solar programs and subsidies provided in comparison with other subsidy programs like LPG, kerosene etc.

This plan also witnessed upgradation of technology for solar photovoltaic cells, which was completed under “Programme Aimed at Technological Self Reliance” (PATSER) promoted by Department of Scientific Industrial Research (DSIR). PATSER aimed at supporting the industries through the development and demonstration of various indigenous technologies [26].

2.8. 10th FYP (2002–2007)

During the 10th FYP (2002–2007) Government of India planned to install a 140 MW Integrated Solar Combined Cycle (ISCC) power plant at Mathania, Rajasthan (Table 3). This project was unduly delayed due to its viability issues and availability of gas to run the hybrid plant during periods of low radiation [27].

During this FYP ‘Village Energy Security' program was approved as a part of remote village electrification. MNES took up pilot projects to provide total energy security to villages, by promoting 900–3000 Wp of capacity pumps which could be used in horticulture. The cost of a solar photovoltaic pump of 1800 W capacity was estimated to be Rs. 2.7 lakh, of which 2/3rd of the cost was subsidized by Ministry of Non-conventional Energy Sources (MNES) for general areas and 90% in case of special areas whereas Indian Renewable Energy Development Agency (IREDA) was responsible for providing soft loans to meet the balance of cost [28].

Further, in an effort to electrify 4000 villages modest target of 5 MW Solar PV decentralized installations were planned. In addition to this, 6 lakhs solar lanterns, 8000 SPV pumps, 10,000 SPV generators, solar water heating systems, cookers and solar air heating systems were also encouraged.

CEL developed Ultra High Efficiency (UHE) solar cells as planned under 6th FYP and further extended their R&D on 250 μm thick silicon wafers and manufacturing of 125 mm/150 mm pseudo square Multi Crystalline Solar Cells (MCSC). This was in addition to R&D work in the area of thin film PV and cells [29].

CEL had also set a target to achieve cumulative solar PV production capacity of 25 MW and produce 40,000 phased control modules per annum during the same plan.

On the other hand Council of Scientific Industrial Research (CSIR) was engaged in development of material technology for solar power and battery application in power sector [29].

Also during this FYP, Government of India promoted community participation (people's participation) to meet and manage the energy requirements in the villages. This ensured the participation of panchayats, local bodies, cooperatives and NGOs, based on this initiative Barefoot Solar Engineers (an NGO) was engaged.

2.8.1. Barefoot solar engineers

Barefoot Solar Engineers (an NGO) is one of the organization's which was engaged in promoting community participation in rural areas. This NGO taught the semi-literate and illiterate rural people on how to harness the sun with the help of solar powered lanterns and photovoltaic systems. It also taught them on how the system works and how it could be repaired. This initiative was also committed in disseminating the information to others in need and to those who can benefit from the green jobs opportunities [30].

Table 4 shows the cumulative installed capacities through solar and its application by the end of the 10th FYP as of 31st March 2007.

Table 4
The potential and achievement as on 31 March 2007.

Sources	Units	Estimated potential	Cumulative achievement
Solar power	MW	50,000	2.92
Remote village electrification	Nos	–	2821/830
Solar photovoltaic programme			
SPV	MW/sq km	20	–
a **Solar street lighting systems**	Nos	–	61,321
b **Home lighting systems**	Nos	–	313,859
c **Solar laterns**	Nos	–	565,658
d **Solar Power plants**	kWp	–	1870
Solar thermal programme			
a **Solar water heating system**	Million sq m collector area	140	1.9
b **Solar Cooker**	Lakh nos	–	6.03
c **Solar PV pumps**	Nos	–	7068

Table 5
Installed capacity till 31st March 2012.

Estimated	Achieved
Grid Connected Installation	
50 MW	939.74 MW
Off Grid Installations	
20 MW	46.64 MW

2.9. 11th FYP (2007–2012)

In 11th FYP (2007–2012) it was believed that solar power can be important in attaining energy independence which is clean in nature and can help the country to reduce GHG emissions. With increasing pressure of climate change and as a responsible developing country, India under its National Action Plan on Climate Change (NAPCC) officially launched Jawaharlal Nehru National Solar Mission (JNNSM) in January 2010. Through this mission India visions to promote solar energy in a very big way to mitigate GHG emissions and map plausible ways to secure energy security by 2022 [29].

The status of actual capacity installed against the planned for 11th FYP which ended on 31st March 2012 is shown in Table 5.

2.10. 12th FYP (2012–2017)

Solar Energy is extremely vital in view of the fact that it is green power with low impact on the environment [31]. The National Solar Mission is a major initiative of Government of India to promote ecologically sustainable growth while addressing India's energy security challenge [32]. In order to make solar power a success in the coming decades, it is vital that we develop the necessary domestic Science and Technology capacity such that we can collaborate as peers with the rest of global community [33].

CEL plans to develop a capacity to manufacture Dye Sensitized Solar Cells (DSSCs or Grätzel cells), which are considered as an alternative to silicon PV thinfilm technologies. It has also proposed to develop more steady design of micro-inverters for connecting to individual solar panels. In additional plans, CEL takes steps to increase the production capacity of 10 MW to 80 MW for SPV products. In an another strategic move it prepares to set up a National Silicon Wafer production facility having a capacity to produce 1000 MW per annum of silicon wafers which will help the country to cut down the dependence on imported silicon materials [34].

CSIR-Network Institute of Solar Energy (CSIR-NISE) is being planned to come up as a new institute for developing the solar energy sector. On the other hand Department of Science and Technology plans out a Solar Energy Research Initiative under which it will support 250 doctoral level researches from 10 institutions. Also Department Atomic Energy (DAE) plans to set up an experimental Solar Test Facility (SOTEF).

Recently Government of India has changed the name of Solar Energy Centre to National Institute of Solar Energy, working as an independent institution for carrying out applied research, demonstration and development in solar energy areas.

3. Government initiative to promote solar energy

Since 2000, there are various initiatives taken by Government of India to encourage solar energy in the country namely, Electricity Act 2003, National Electricity Policy 2005, Tariff Policy 2006 and its amendment in 2011, National Action Plan on Climate Change 2008, Semiconductor Policy 2007 and Karnataka Semiconductor Policy 2010. Also 14 states have announced their State specific solar policies till date (April 2014).

Fig. 1 depicts the different policies announced by Central and State governments to promote solar energy in the country and in the following sections the salient features of these regulations and policies have been discussed.

3.1. Electricity Act, 2003

It outlines several enabling provisions to accelerate the development of RE based generation such as [35]:

- (Section 3): it states that “under the National Electricity Policy Plan, Central Government in consultation with the State Government will develop policy and plans for development of power system based on renewable sources of energy and other conventional energy sources.”
- (Section 61(h)): it states that “the appropriate commission shall specify the terms and conditions for determination of tariff and in doing so, shall promote generation of electricity from renewable sources of energy in their area of jurisdiction.”
- (Section 66): “Appropriate Commission shall endeavor to promote the development of market (including trading) in power in such a manner as may be specified and shall be guided by National Electricity Policy in Section 3 in this regard.”
- (Section 86(1)(e)): “The State Electricity Regulatory Commissions to specify **minimum** Purchase Obligation from renewable sources of energy out of total consumption of energy (a percentage of the total consumption of electricity in the area of a power distribution company).”

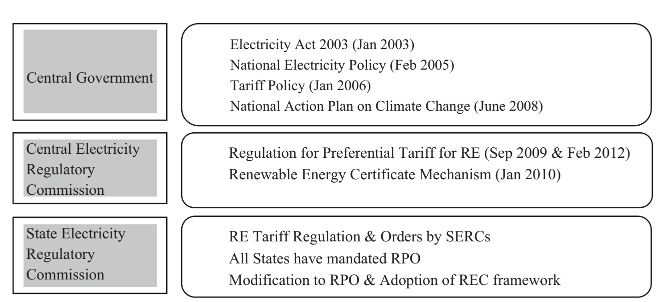


Fig. 1. Snapshot for different regulations & policies by Central & State Government.

- (Section 86(1)(e)) reads as "promote cogeneration and generation of electricity from renewable sources of energy by providing suitable measures for connectivity with the grid **sale of electricity to any person**, also specify, for purchase of electricity from such sources, **a percentage of the total consumption of electricity** in the area of a distribution licensee"
- Further, while discharging its mandatory function the Central Electricity Regulation Commission (CERC) issued "Terms and Conditions for Tariff determination from Renewable Energy Sources Regulations" in September 2009 which was applicable till March 2012. For the subsequent years CERC notified "Terms and Conditions for Tariff determination from Renewable Energy Sources Regulations" in February 2012 for a control period from April 2012 to March 2017. In these Regulations CERC defined the Tariff design, which ensures an assured return with full cost recovery during debt repayment period for the developer. The tariff period for Solar, will be up to the useful life of the plant which is 25 year
- The Tariff Structure defined in the said regulation as the Single part levellised generic tariff consisting of the following components:
  (a) Return on equity;
  (b) Interest on loan capital;
  (c) Depreciation;
  (d) Interest on working capital;
  (e) Operation and Maintenance expenses;

The following Tables 6 and 7 show the tariffs announced by CERC every year since 2009.

3.2. National electricity policy (February 2005)

Specify that, "share of electricity from renewable sources would need to be increased progressively, purchase for distribution companies will rely on competitive bidding basis. Commission needs to determine an appropriate differential tariff to promote these technologies, as they will take some time to compete with conventional sources on basis prices" [42].

3.3. Tariff policy (January 2006)

Government of India announced the Tariff Policy on 6th January 2006 in accordance with Section 3 of Electricity Act 2003, it states that appropriate Commission (State Electricity Regulatory Commission) shall fix Renewable Purchase Obligation (RPO) and shall also fix the technology specific tariff for different renewable sources of energy. The Tariff Policy provided that, initially the appropriate Commission is to fix preferential tariffs for distribution utility to procure Renewable Energy (RE), in future, distribution utility to procure RE technology through competitive bidding within suppliers offering same type of RE. In long-term, RE technologies are expected to compete with all other sources in terms of cost [43].

3.3.1. The amendment in tariff policy 2011 [44]

- SERCs shall fix **separate RPO** for purchase of energy by the Obligated Entities from **Solar Energy Source**
- **Solar RPO** to go up to **0.25% by the end of 2012–13** further up to **3% by 2022**

Table 6
Solar PV tariff determined by central electricity regulatory commission.

Date of order	Order no.	Applicable year	Benchmark capital cost [Lakh*/MW]	Levellised generic tariff for 25 years	
				Without accelerated depreciation [Rs./kWh]**	Availing accelerated depreciation Rs./kWh]**
03–12–2009	248/2009 [36]	FY 2009–10	1700	18.44	17.14
26–04–2010	53/2010 [37]	FY 2010–11	1690	17.91	14.95
09–11–2010	255/2010 [38]	FY 2011–12	1442	15.39	12.94
27–03–2012	35/2012 [39]	FY 2012–13	1000	10.39	9.35
28–02–2013	243/SM/ 2013 [40]	FY 2013–14	800	8.75	7.87
07–01–2014#	SM/353/ 2014 [41]	FY 2014–15	612	6.99	6.33

* 1 Lakh = 0.1 Million.
** Rs./kWh = Indian rupees per kilo watt hour of solar energy.
Draft order, final order yet to be issued.

Table 7
Solar thermal tariff determined by central electricity regulatory commission.

Date of order	Order no.	Applicable year	Benchmark capital cost [Lakh*/MW]	Levellised generic tariff for 25 years	
				Without accelerated depreciation [Rs./kWh]**	Availing accelerated depreciation [Rs./kWh]**
03–12–2009	248/2009 [36]	FY 2009–10	1300	13.45	12.54
26–04–2010	53/2010 [37]	FY 2010–11	1530	15.31	12.85
09–11–2010	255/2010 [38]	FY 2011–12	1500	15.04	12.69
27–03–2012	35/2012 [39]	FY 2012–13	1300	12.46	11.22
28–02–2013	243/SM/ 2013 [40]	FY 2013–14	1200	11.90	10.69
07–01–2014#	SM/353/ 2014 [41]	FY 2014–15	1200	11.89	10.70

* 1 Lakh = 0.1 Million.
** Rs/kWh = Indian rupees per kilo watt hour of solar energy.
Draft order, final order yet to be issued.

Table 8
State specific solar policies.

S.No	State	1 Policy Name	2 Operative Period	3 Capacity Planned	4 Tariff (Rs/kWh) (AD-Accelerated depreciation)	5 Categort / Types of Projects	6 Current Installed Capacity (MW)	7 Off Taker	8 Radiation kWh/m2/ day	9 Nodal Agency	10 Incentives
1	***Andhra Pradesh***	Andhra Pradesh Solar Policy 2012	2012–2017	No official Declaration	***Solar PV*** – 17.91 (w/o AD); 14.95 (with AD); (Upto 2011–12, No Tariff Notified for 2014-15) ***Solar Thermal*** – 15.31 (w/o AD); 12.85 (with AD) (Upto 2012-13, No Tariff Notified for 2014-15)	Competitive Bidding; Captive/ Open Access; REC; JNNSM	131.84	APDISCOM	5.5–6	NREDCAP	100% Energy Banking; Electricity Duty Exemption; No Wheeling & Transmission charges; VAT, Stamp Duty and Land Registration Refund; Exemption of Cross Subsidy Surcharge
2	***Chhattisgarh***	Chhattisgarh State Solar Policy 2012	2012–2017	1000	***Solar PV*** – 8.69; (Upto 2013–2014) (Draft Tariff for 2014–2015 – 7.74) ***Solar Thermal*** – 11.82 (Upto 2013–2014) (Draft Tariff for 2014–2015 – 11.91)	Competitive Bidding; Captive /Open Access; REC	7.1	CSPDCL	4.5–5.5	CREDA	Conditional Energy Banking; Electricity Duty Exemption; VAT, Stamp Duty and Land Registration. Exemption and Interest Subsidy
3	***Gujarat***	Solar Power Policy 2009	2009–2014	500	***Solar PV*** - 8.39 (with AD); 9.44 (w/o AD) (Upto 2014–2015) ***Solar Thermal*** – 11.83 (with AD); 13.23 (w/o AD) (Upto 2014–2015)	Competitive Bidding; Feed in Tariff; Open Access	916.4	GUVNL	6.5–7	GEDA	Exemption from Demand cut upto 50%; Electricity Duty Exemption; Cross Subsidy Surcharge Exemption
4	***Jammu and Kashmir***	Jammu and Kashmir Solar Energy Policy 2013	2013-till further notification	1300 MW (Grid Connected 33 kV – 1000 MW; Rooftop PV and Small Solar 100 MW; Off – Grid Applications 200 MW)	***(Draft Tariff for 2014–2015) Solar PV –*** 6.07 (with AD); 6.78 (w/o AD) ***Solar Thermal*** – 10.29 (with AD); 11.57 (w/o AD)	RPSSGP; JNNSM	–	PDD	4.5–7.5	JAKEDA, LREDA, KREDA	No entry tax by the State on equipments of the plant; Government land will be faciliated (if required); Stamp Duty exemption; Exemption from Court fee for registration of documents; Exemption from Demand cut upto 50%
5	***Jharkhand***	Jharkhand Solar Policy 2013 – Draft	2013-2018	500 MW – 2017; 1000 MW – 2022	***Solar PV*** - 17.96 (w/o AD); 14.98 (with AD) (Upto 2010-11, No Tariff Notified for 2014-15) ***Solar Thermal*** – 13.12 (w/o AD); 11.02 (with AD) (Upto 2010-11, No Tariff Notified for 2014-15)	Competitive Bidding; Captive /Open Access; REC; JNNSM	16	JSEB	4.5–5.5	JREDA	100% Banking
6	***Karnataka***	Karnataka solar policy 2014–2021	2014–2021	2000 MW	(Tariff Upto 2018) ***Solar PV*** – 8.40; ***Solar Thermal*** – 10.92	Competitive Bidding; Captive/ Group Captive/ Open Access; REC; IPP; Bunddling Scheme	31	ESCOM	5.5–6.5	KREDL	Tax Concessions on Entry Tax, Stamp Duty and Registration Exemptions; Central Excise and Custom Duty Exemptions
7	***Kerala***	Kerala Solar Power Policy 2013	2013 till further notification	500 MW; 2500 MW – 2030	***Solar PV*** – 17.91 (w/o AD); 14.95 (with AD) (Upto 2012, No Tariff Notified for 2014-15) ***Solar Thermal –*** 15.31 (w/o AD); 12.85 (with AD) (Upto 2013, No Tariff Notified for 2014-15)	Competitiv Bidding; Feed-in-Tariff; IPP; REC	0.025	KSEB	-	ANERT	Conditional Electricity Banking; Evacuation Facility; No charge on Open Access; No Wheeling charges and T&D losses for Captive plants; Exemption of Electricty Duty
8	***Madya Pradesh***	Madya Pradesh Solar Policy 2012	2012-2017	No official Declaration	(Tariff Upto 2014) ***Solar PV*** – 10.70 for Upto 2 MW; 10.44 for above 2 MW; ***Solar Thermal*** – 12.65	Competitive Bidding; Captive /Open Access; REC; JNNSM	347.165	MP Discom/ MP Power Management Co Ltd.	5.5	Office of Commissioner New & Renewable Energy. MP	50% exemption on Stamp Duty; 10 years Electricity Duty & Cess charges exemption from COD; 100% Electricity Banking; VAT and Entry tax Exemption; Wheeling charge Exemption – GoMP will provide 4% grant in terms of energy injected to the developer
9	***Orissa***	Odisha Solar Policy 2013-Draft	2013–2017	No official Annoucement	***Solar PV*** -17.80 (w/o AD); 14.77 (with AD) (Upto 2012, No Tariff Notified for 2014-15) ***Solar Thermal*** – 14.73 (w/o AD); 12.32 (with AD) (Upto 2012, No Tariff Notified for 2014-15)	Competitive Bidding; Captive/ Open Access/IPP; REC	30.5	GRIDCO	5.4-5.6	OREDA	Electricity Duty Exemption
10	***Punjab***	New & Renewable Sources of Energy Policy 2012	2012–2017	200 MW	(Tariff Upto 2014–2015) ***Solar PV*** – 7.72 (w/o AD); 6.95 (With AD); ***SolarThermal*** - 11.88 (w/o AD); 10.65 (With AD)	Competitive Bidding; Captive /Open Access; REC; JNNSM; RPSSGP	16.845	PSPCL/DL	4.5–6.5	PEDA	Conditional Energy Banking; Electricity Duty Exemption; VAT, Octroi, Stamp Duty, Land Registration and Entry Tax Exemption
11	***Rajasthan***						730.1		6.5–7	RRECL	

Table 8 (*continued*)

S.No	1	2	3	4	5	6	7	8	9	10
State	**Policy Name**	**Operative Period**	**Capacity Planned**	**Tariff (Rs/kWh)** (AD-Accelerated depreciation)	**Categort / Types of Projects**	**Current Installed Capacity (MW)**	**Off Taker**	**Radiation kWh/m2/ day**	**Nodal Agency**	**Incentives**
	Rajasthan Solar Energy Policy 2011	2011-Till further annoucement	200 MW- Phase 1 (upto 2013); 400 MW -Phase 2 (upto 2017)	(Tariff Upto 2013–2014) ***Solar PV*** – 8.33 (w/o AD) ; 7.31 (with AD); ***Solar Thermal*** – 11.37 (w/o AD) ; 9.97 (with AD)	Competitive Bidding; Captive /Open Access; REC; JNNSM; RPSSGP		Rajasthan Discom			Eligible for incentives under Industrial policy; Electricity Duty Exemption
12 ***Tamil Nadu***	Tamil Nadu Solar Energy Policy 2012	2012-2015	1000MW - 2013; 1000MW - 2014; 1000MW - 2015	(Tariff through Competitive Bidding only) (Tariff Discovered through bidding in 2013-2014, No Tariff Notified for 2014-15) ***Solar PV*** - 5.78; ***Solar Thermal*** - 8.34	Competitive Bidding; REC	98.36	TANGEDCO	5.6-6.0	TEDA	Electricity Duty Exemption for 5 years from COD; 50% Stamp Duty exemption on Government Industrial Parks
13 ***Uttrakhand***	Solar Energy Policy of Uttrakhand 2013	2013-Till further notification	500MW - 2017	(Tariff Upto 2013, No Tariff Notified for 2014-15) ***Solar PV*** - 11.10 (w/o AD) ; 10.15 (with AD); ***Solar Thermal*** - 13.30 (w/o AD) ; 12.15 (with AD)	Competitive Bidding; Captive on Private Land; Captive on Government Land; JNNSM	5.05	UPCL	4.5-5.5	UREDA	VAT and Entry Tax Exemption
14 ***Uttar Pradesh***	Uttar Pradesh Solar Power Policy 2013	2013-2017	500MW -2017	Tariff to be discovered through Competitive Bidding only	Competitive bidding; Captive / Open Access	21.075	UPPCL	4.5- 6.5	UPNEDA	

- Purchase of energy from non-conventional sources of energy to take place more or less in same proportion across different States
- Renewable Energy Certificate (REC) Mechanism may be one of the mechanisms to achieve such target

3.4. National action plan on climate change (NAPCC) – 2008

It earmarks the National level target for RE Purchase from 5% of total grid purchase in 2010 to 15% by 2020 by increase of 1% each year for next 10 years from 2010. Different SERCs of respective states may set higher target independently. It also authorizes appropriate authorities to issue certificates that procure RE in excess of the national grid, which may be tradable, to enable utilities falling short to meet their obligation of renewable energy purchase (RPO) [45].

4. Policy to encourage semiconductor industry

4.1. Semiconductor policy 2007

This policy was announced by Government of India to draw investments in semiconductor fabrication by providing special incentives for manufacturing of all semiconductors and solar photovoltaic cells [46].

4.2. Karnataka semiconductor policy 2010

Government of Karnataka took an early mover advantage to become the first State to announce its semiconductor policy to encourage solar energy sector. The State government focused on entire value chain of solar energy, as it provided enabling policy to attract investments in manufacturing of Solar PV cell, Assembly-Test-Mark-Pack plant (ATMP) and Wafer production facility.

Under the central policy for semiconductor, Andhra Pradesh and Tamil Nadu were drawing maximum investments as they provided additional incentives and subsidies to entice the firms, till Karnataka became a hub for production of solar products such as solar water heating systems, solar PV modules and various components required by the sector, when it introduced its own State specific policy. The Semiconductor policy was supported by Karnataka Renewable Energy Policy which aimed at providing support and assistance to Solar PV manufacturing units in State.

Karnataka Power Corporation (KPC) along with Karnataka Renewable Energy Development Limited[4] (KREDL) plans to develop Solar Farms on Joint Venture/PPP mode in identified districts of Bijapur, Gulbarga, Raichur and Bellary. The State also visions to electrify schools with solar power through Education policy. The government further plans to create a core group for activities related to liaising with stakeholders to promote the sector in State [47].

5. State specific solar policies

In an effort to promote solar energy, some States took a positive step to announce their State specific solar policy. Gujarat took the first mover's advantage by becoming the first State to announce its policy in 2009, with its supporting environment for the investors the State is currently the leader in terms of installed capacity. Since 2009 there are now 14 States which have announced such policy. Table 8 discusses all 14 policies under different categories, these are:

[4] *KREDL is the nodal agency for promoting the RES in the state*

- Policy name.
- Operative period of policy for which it will remain into power.
- Capacity (planned) to be installed during the operative period.
- Tariff announced by the respective SERC's.
- Category of the project under which power plants will be installed.
- Current installed capacity of the State.
- Off-taker for power produced or the agency to sign Power Purchase Agreement (PPA) with generator.
- Nodal agency in the State.
- Incentives provided to the generator and
- Measured radiation for the State.

After Government of India declared JNNSM in the year 2010, Karnataka and Rajasthan came up with their Solar policy in 2011, likewise Andhra Pradesh, Chattisgarh, Madhya Pradesh, Punjab and Tamil Nadu announced their solar policies in 2012 followed by Jammu and Kashmir, Jharkhand, Kerela, Uttar Pradesh and Uttrakhand who had released their policies in the year 2013. Currently Odisha is waiting for approval on the draft solar policy which was not finalized till the time this study was conducted.

Table 9
Compiled technical barriers to solar energy.

Technical barrier	Variables	Inference
GHI/DNI	Lack of reliable of data [48,49] Lack of accurate data [50]	
Technology	Intermittency of the source [51] Storage issues [52] Low efficiency [53] System & Technology risk [54] Diffusion of foreign technology [55] Design & ease of operation [56]	There is low level of technological maturity. Performance risk is associated with the technology. Availability of parts & ancillaries
Infrastructure deficiencies	Evacuation system [51] Non up gradation of substation [52] Limited rooftop area & building integration [57]	Remote area grid connectivity Interconnectivity issues

6. Issues to "Growth of Solar Energy"

Post-independence India has witnessed many initiatives and programs specific to solar energy to address energy security and simultaneously reducing the carbon footprints, however, the impact of these programs have been very marginal. It is apparent from the review of five year annual plans since 1950, that solar energy in India has been actively promoted only since 2009 with specific solar policies at national and State level.

The current capacity of solar energy in India stands close to 2.2 GW (inclusive of grid and off grid installation). Under the country's ambitious initiative – National Solar Mission, aims to install 22 GW of capacity by 2022, but this roadmap will not be easy as there are many issues which need to be answered through strong policy and proactive measures, in a way that the effectiveness of these initiatives and programs are highlighted.

The authors feel that there are numerous barriers and challenges which will act as road blocks for promoting solar energy in the country. In a process of finding out the dimensions to different barriers and challenges, the authors have made an effort to summarize these barriers and challenges and categorized them as Technical barriers, Policy barriers, Socio-economic challenges and Institutional challenges. The variables found have been chronic across different countries. Some of these variables need to be assessed in India as per its demographics and market, also to which the mitigation strategies should be worked out.

6.1. Barriers and challenges

The sorted barriers and challenges have been divided into factors, which are further expanded into different variables and their observations.

6.1.1. Technical barriers

The technology is surrounded by many technical issues and uncertainties, such as storage issues, the risk associated with technology and its related system, the inadequacy and reliability of the DNI data available and many others have always been a matter of debate. Due to these concerns it has become difficult for solar to be competitive with other more established sources of energy. The concerned factors have been depicted in Table 9.

Table 10
Compiled policy & regulatory barriers for solar energy.

Policy & regulatory barriers	Variables	Inference
Policy	Issues in clarity of policy [51] Absence or inadequate specific policy & legal support framework for promotion of the technology [55] Lack of financial incentives [49] Policy for market creation, capital grants [58] Lack of strong implementation/enforcement of policies [59,77,] Water allocation issues, Land allocation issues [51] Lack of adequate financial incentive mechanism [49,52] [50] Easy access to cheap fossil fuels [53]	There is policy uncertainty among the stakeholders Issues in clarity of installation plan policy Lack of country assistance strategies Lack of suitable support mechanism Lack of appropriate financial intermediaries & incentives for small scale decentralized energy services Issues & access to funds & subsidies by the government Direct & indirect subsidies to competing fuels/conventional fuels
Regulatory	Capital cost benchmarking by the regulator [51] Utility interconnection issues [55] Lack of effective laws & regulation for power generation Regulation for strong enforcement of guidelines [60]	 Issue in integrated power sector reforms Adequate legal guidelines for independent power producers

Table 11
Compiled socio-economic challenges to solar energy.

Scio-economic challenges	Variables	Inference
Financing	High initial capital cost [61–64]	
	Limited access to affordable credit [65,60]	Difficulty in availing buyer's credit
	Difficulty in availing project finance [66]	If the project finance is available then it is at a higher interest rate.
		Long payback period of the project
	Difficulties related to bankability of the project related agreements [13,67]	e.g. Bankability of the Power Purchase Agreement for solar power project
	Transaction cost is high for technology commercialization [66,68,55]	Dependency on the national budget. There are limited financial incentives.
	Weak industry networks [54]	It raises the market insecurity
Market	Existence of informal & unqualified PV manufacturers & operators [69]	This a cause of less in number of local manufacturers
	Difficulties in technology dissemination due to inadequate market infrastructure, sales & service networks [66]	Which is a cause of weak industry networks
	Challenges related to supply of silicon [57]	Many countries are dependent on the imported silicon
	Lack in numbers for similar kind of projects [57]	It is because there are less number of demonstration projects & their low replication
	The fragileness of partnerships for solar development [57]	This leads to high risk perception of private investor
	Lack of community participation [49]	Theft & vandalism of equipment can be one of the results of it
	Issues with social & cultural attitudes [56]	There is still low social acceptance for solar technology.
		Local level disturbance leads to hindrance in the solar market.
		Lack of social policy
Awareness & ***acceptability***	Lack of technology awareness and its benefits among different stakeholders [70]	
	Political instability at different levels	Conflicting political priorities can be one of the reasons of it.
	Lack of attention by the policy makers [71]	Lack of vision among the politicians & their advisors
	Power utilities unwillingness to adopt innovative approaches [72]	Unawareness towards the impact on environment & society by the conventional source of energy
		Biasness towards conventional energy
	Affordability by the weaker section of the society because of low income [73]	
	Cost of storage or backup utilities is high [58]	
Cost	Risk related to pre-investment cost [66]	
	Cost of balance of system [BoS] are somewhat saturated [57]	
	Exclusion of environment externalities in cost of generation of electricity from the fossil fuel [55,66]	Lack of fuel risk assessment by the respective agencies
		Comparison of cheap fossil fuel to free renewable fuel on the base of technology cost
	Preference towards centralized source of energy generation [65]	
	Import tariff [58,66]	Trade barriers impose high import duties
Land	Lack of land availability	Continuous land for large solar projects. Contour of land
	Non availability of adequate data on land title/ ownership [49]	Lack of data on land/ property registry
	Complex area zoning & planning by the local government [52]	Difficulties in acquiring land
	Lack of data on potential sites [74]	
	Ease of right	Access to land & its use. Right of Way [RoW], Right of Water [RoW]
	Reserved or protected area in proximity of the project [52]	Use management of protected areas
	Inadequate installation space & service infrastructure [71]	

6.1.2. Policy and regulatory barriers

To grow consistently solar energy sector requires supportive policies and encouraging regulations. The investors show reluctance and uncertainty if they perceive high risk in the sector, which can only be assured by strong and attractive policies for developing a market. The lack in clarity of policies and regulations can adversely affect the long term development planning of a country. Table 10 shows the related policy and regulatory barriers for solar energy sector.

6.1.3. Socio-economic challenges

The Socio-Economic challenges have a strong impact on the development of solar energy, as it can leads to less adoption and acceptance of the technology. It is a hard fact that the technology requires huge investment which alone cannot be fulfilled through sovereign funds, so there is need to draw private investments, which can only be attracted when there are favorable incentives to invest in the technology. There are concerns to availability of affordable credit, as the market is not mature enough to help attract investments for development of the sector. There are challenges related to availability of land, non-availability of adequate data on land title / ownership, complex area zoning and planning done by local bodies, there are issues pertaining to easement of rights on reserved or protected areas in proximity of the project and likewise some of the important Socio-economic challenges are listed in Table 11.

6.1.4. Institutional challenges

The government organizations and other institutions play important role in developing and promoting a technology in a country. In India, we have seen organizations like IREDA, CASE, SAP etc., being setup to promote renewable, but impact of these initiatives have not been promising. In fact a well-functioning institution can alone solve many challenges for solar to grow steadily. Table 12 covers factors pertaining to institutional challenges, concerns relating to human resource development, dissemination of information and the level of existence of research and development.

7. Future directions

In this section authors have proposed some initiatives as future directions for India which can be adopted in the said key areas in

Table 12
Compiled institutional challenges for solar energy.

Institutional challenges	Variable	Inference
Resource development	Insufficient training & research institute [69,56,61,75]	Limited ability to train adequate number of technicians
	Lack of specialized courses on RET engineering [73]	Insufficient expertise to specific technology
		Lack of information on installation & maintenance training
	Shortage of commercial & technical trained workforce [76,64,71]	
Research & ***development***	Lack of financial support & incentives to R&D activities [77]	Limited interest towards RET R&D in the country
		Limited prospects in R&D
	Difficulties in RET technology exchange across borders [73]	Lack in responsibility towards RET R&D
Information exchange	Lack of experience & understanding among financial institutes [60]	Knowledge diffusion barrier among financial institutes/ banks for RET
	Lack of knowledge sharing between different stakeholders towards RET [51,54]	
	Limited efforts to disseminate information/knowledge on benefits & adverse effects [Health, Environment, Economy] [73]	Insufficient sources for information diffusion
	Limited access to information on successful projects [73]	
Institution	Multi-tiered government approvals [57,52]	Lack of information on true RET cost
		Complex administrative procedures
		Long delay in authorization
		Lengthy regulatory & permit approvals
	Non-standardization of technologies leading to low level of reliability [71,65,60,66]	Lack of common code or standards
	Non-functioning of agencies at local level	Poor management of state enterprises
		Lack of coordination among federal & states
	Lack of specialist/experts among decision or policy makers [60,69]	
	Insufficient centers for measuring accurate radiation for a place or specific latitude & longitude [74]	

an attempt to mitigate some or most of the barriers and challenges as found in the review. These suggestions are as under:

- Introduction to innovative financing mechanism to encourage investments in the solar sector. (e.g. Introduction of Solar Bonds in the country).
- Introduce guidelines for strong implementation of purchase obligation. (Enforcement of RPO's).
- Manufacturing of cells modules can be supported by introduction of novel instrument to reduce the cost of input factors which can reflect on the final cost of the product.
- Have more awareness and adoption programs run across the country through print, electronic or new age media which are very cost effective.
- Introduction of certificate courses and training programs for developing human resource in the field of solar energy at national and regional level. (e.g. India has establish a National Institute of Renewable Energy (SSSNIRE) under MNRE which primarily focuses on research and developments in the area of bio-energy) [78].
- Creation of national funds for incentivizing research and development in area of solar energy.

8. Conclusion

Development of solar sector in India has been visible, through different initiatives, ever since independence. Solar saw the transition from a mere obligation to uplift society to a stronger socio-economic growth opportunity in India. However, solar requires supportive policies for its continuous growth before it can sustain on its own. Solar has become more of a business proposition for investors in the country and equally contributing to the development of economy, as its returns are visible three fold i.e. economically, socially and environmentally. As the sector is growing there are lots of lessons to be learnt from the internal and external environment and from our previous short falls, which can be corrected with the help of innovative methods.

Through this paper authors have tried to discuss the journey for solar energy in India since 1950 till date and highlight the potential barriers and challenges which can impact the ambitious missions taken up by Central and State governments.

Further, there are lots of issues emerging out of the discussions in the current review, some of them require immediate attention that can support in mitigating the potential barriers and challenges and provide impetus to solar initiatives in India.

Some of the suggestive measures that can be taken up are as under:

- Develop robust partnerships with developed countries for diffusion of technology and its development in the area of solar energy. For example in recent past, India has inked various MoU's with other countries like USA, Germany, Australia, United Kingdom, Japan etc. for developing and exchanging knowledge on different technologies in field of renewable and non-renewable energies [79,80].
  Recently India has signed a MoU with UAE to promote co-operation in the area of RE, with major emphasis being on the development of solar energy and wind energy. The key highlights of this MoU states that, both countries will contribute in exchange and training of scientific and technical personnel, information and data transfer of know-how in the related technologies [81].
- Acquiring more reliable and accurate ground level data of solar radiation specific to longitude and latitude of a place.
- Smart utilization of land for developing solar power plants, as India has large area under cultivation. There have been initiatives in the country to optimally utilize the space for developing solar power plants for e.g. in Gujarat, a State in India, a 1.1 MW solar PV power plant has been developed over Narmada canal, which has not only saved land engagement, but also helps in saving 7 million liters of drinkable water annually [82]. In an another effort to optimize land usage government of Bihar, a State in India, had called for RFP for setting up a cumulative capacity of 150 MW grid tied solar PV power plants along with Pisci-culture. This innovative thought will not only help in generating power but also help in shading the ponds on

high temperature days and improve the productivity of fish farming [83].

- Actively promote manufacturing across the value chain of solar industry so as to compete with international market and reduce our dependency on China, USA, Taiwan, and Germany.
- Streamline the process of institutional procedures for an end-user for availing the subsidies on buying of modules.
- There is need to prioritize the sector without getting it affected by political instability.
- Enforce full implementation of Single window clearance at state level.

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